J-PARC Muon Facility Proposal

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Fermilab Proton Driver Workshop
October 7th, 2004

Outline

- Muon Physics Programs
  - Physics Motivation
  - Muon g-2, Muon EDM, Muon Lepton Flavor Violation (LFV)
- New beam schemes
- J-PARC Muon Facility (Muon Factory)
  - Layout
  - Proton beam
  - LOI
  - Present status and next step

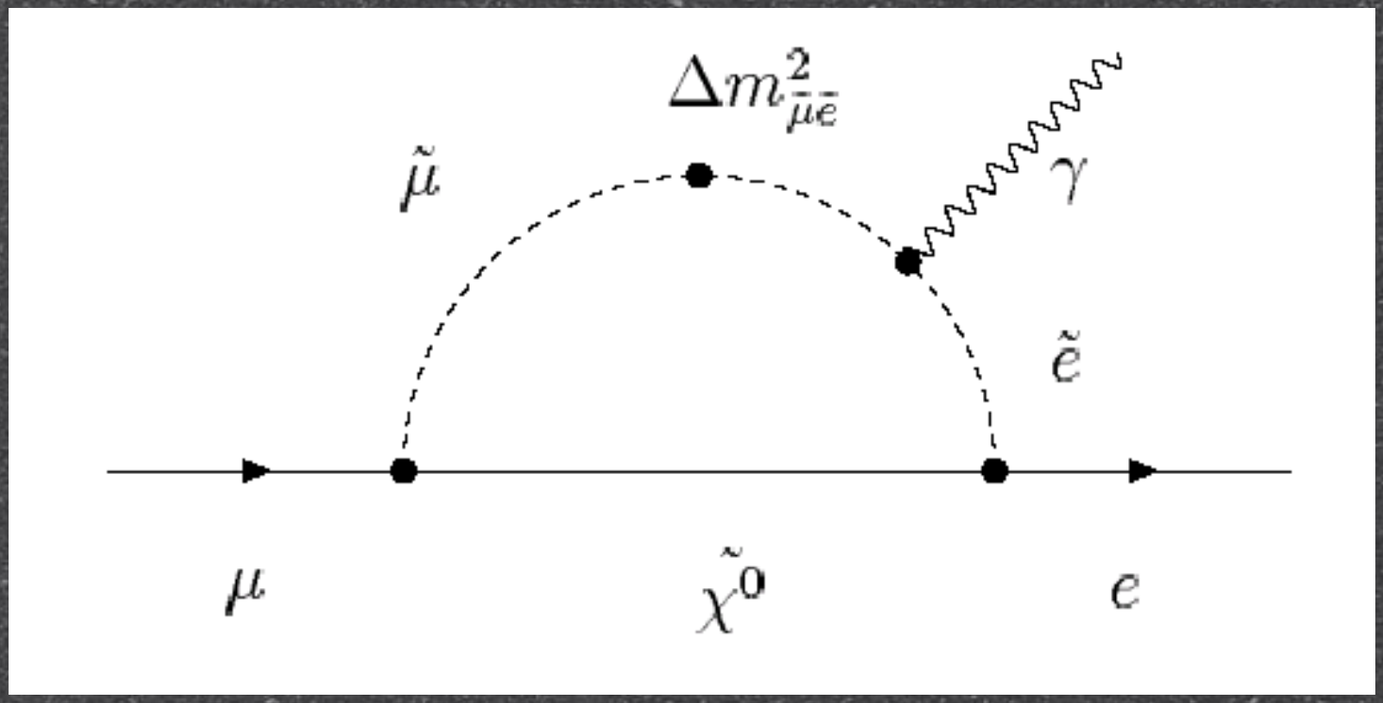
Muon Programs

Why Muon Particle Physics?

The muon system is one of the best place to search for physics beyond the standard model.

Process	In Standard Model
muon lepton flavor violation	forbidden process
muon EDM	suppressed process
muon g-2	precise measurement

LFV and SUSY



In SUSY models, LFV processes are induced by the off-diagonal terms in the slepton mass matrixes.

$$m^2_{\tilde{l}} = \begin{pmatrix} m^2_{11} & m^2_{12} & m^2_{13} \\ m^2_{21} & m^2_{22} & m^2_{23} \\ m^2_{31} & m^2_{32} & m^2_{33} \end{pmatrix}$$

Off-diagonal terms depend on how SUSY breaking is generated and what kinds of LFV interactiosn exist at the GUT scale.

Slepton Mixing Mechanisms

$$(m^2_{\tilde{l}})_{ij} = m^2_0 \delta_{ij}$$ @ M_planck

SUSY-GUT

GUT Yukawa interaction

SUSY Seesaw Model

Neutrino Yukawa interaction

$$(\Delta m^2_{\tilde{l}})_{ij} \neq 0$$

$$(m^2_{\tilde{L}})_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_t^2 V_{td} V_{ts} \ln \frac{M_{GUT}}{M_{R_s}}$$

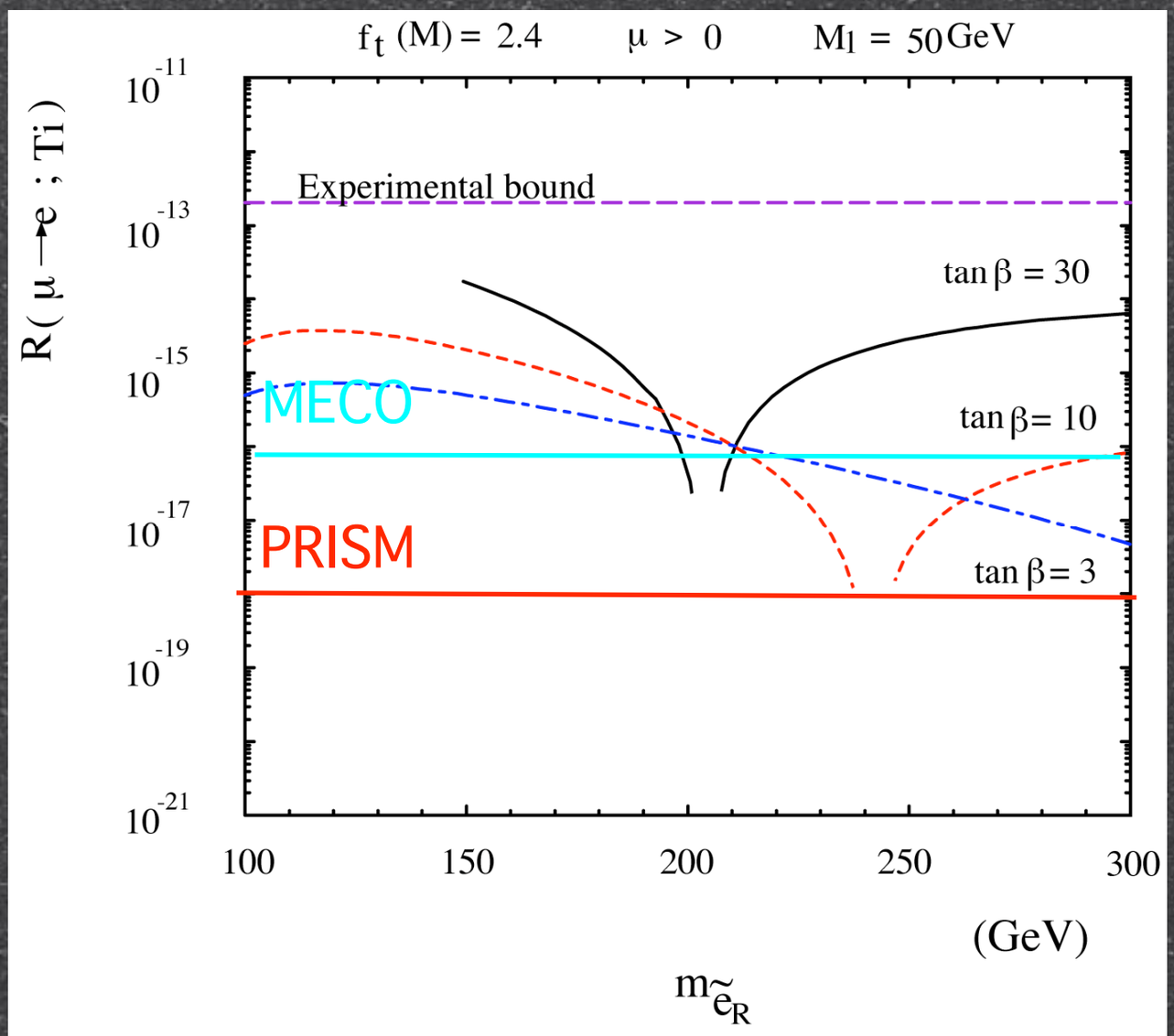
CKM matrix

$$(m^2_{\tilde{L}})_{21} \sim \frac{3m_0^2 + A_0^2}{8\pi^2} h_t^2 U_{31} U_{32} \ln \frac{M_{GUT}}{M_{R_s}}$$

Neutrino oscillation

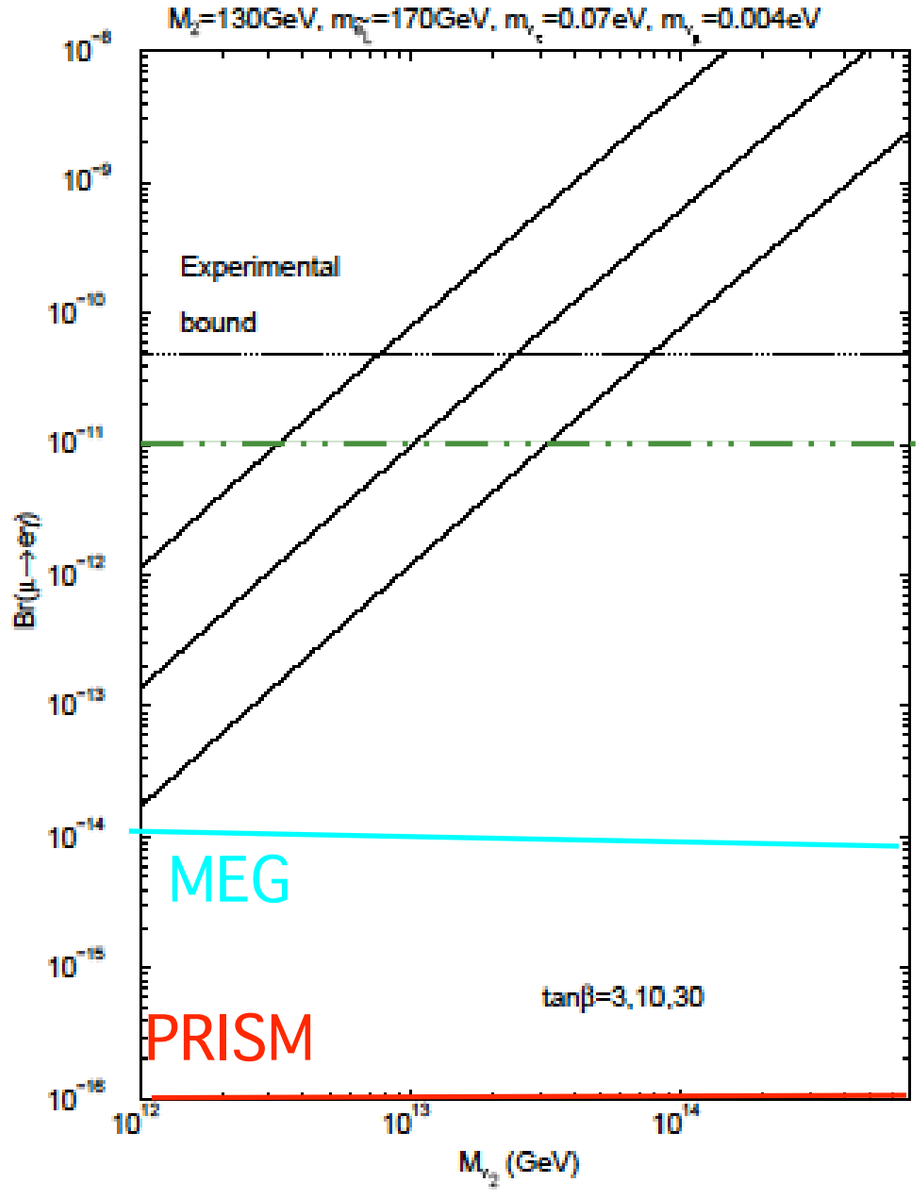
SUSY LFV Predictions

SUSY-GUT



Branching ratios can be large in SO(10) SUSY GUT model

SUSY Seesaw Model



LFV Catalog

For the muons,

ΔL=1

- $\mu^+ \to e^+\gamma$
- $\mu^+ \to e^+e^+e^-$
- $\mu^- + N(A,Z) \to e^- + N(A,Z)$
- $\mu^- + N(A,Z) \to e^+ + N(A,Z-2)$

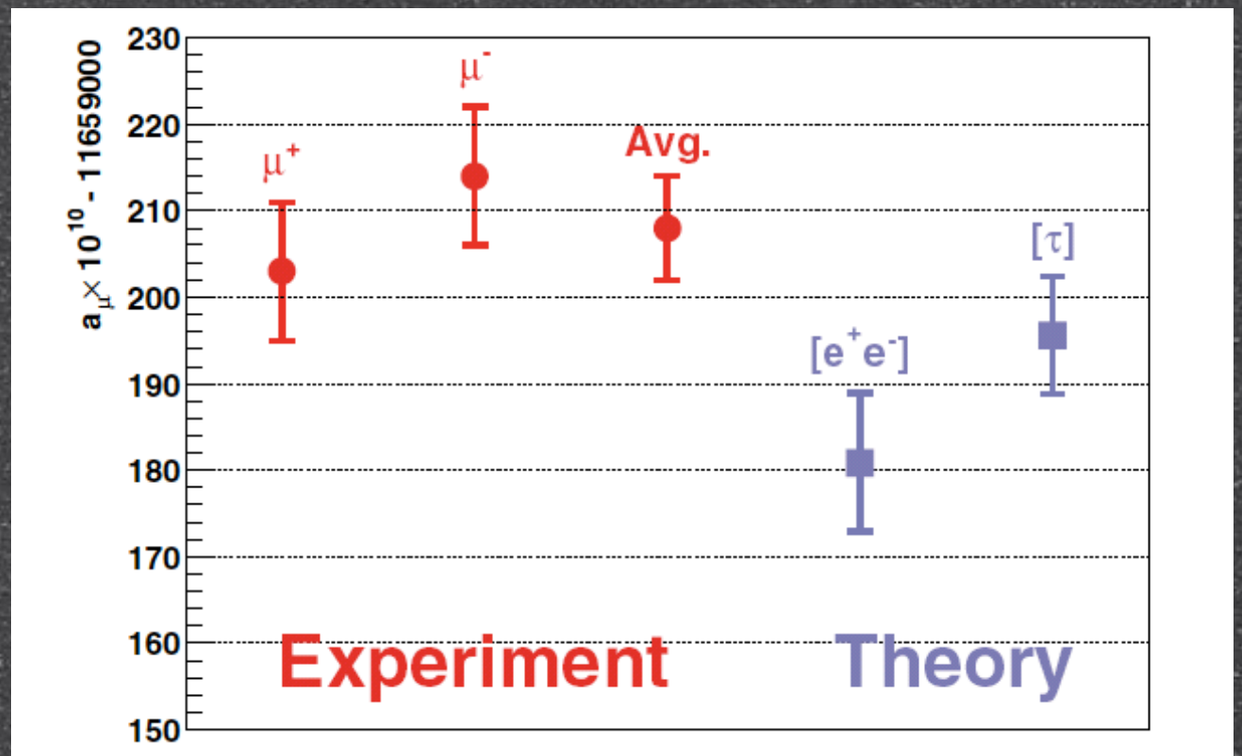
ΔL=2

- $\mu^+e^- \to \mu^-e^+$
- $\mu^- + N(A,Z) \to \mu^+ + N(A,Z-2)$
- $\nu_\mu + N(A,Z) \to \mu^+ + N(A,Z-1)$
- $\nu_\mu + N(A,Z) \to \mu^+\mu^+\mu^- + N(A,Z-1)$

Which Muon LFV Process Next ?

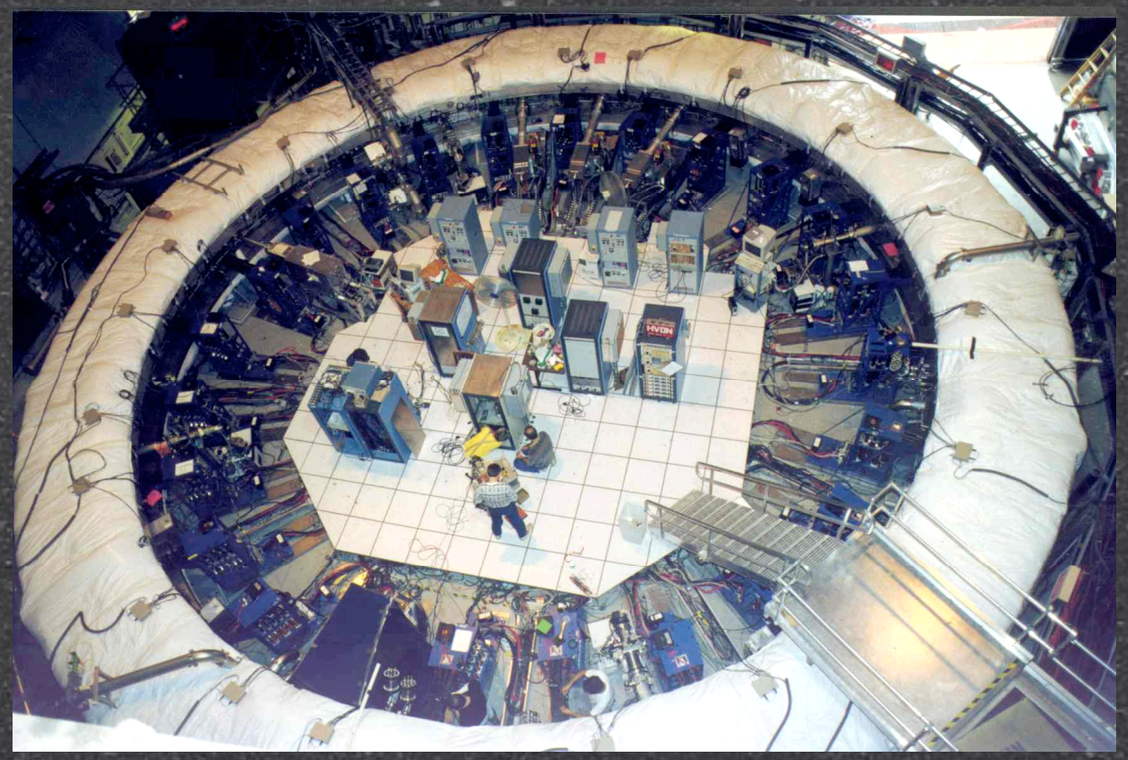
	issue	beam requirement
$\mu \longrightarrow e\gamma$	detector-limited	a continuos beam
$\mu \longrightarrow eee$	detector-limited	a continuos beam
$\mu N \longrightarrow eN$	beam-limited	a pulsed beam

Muon g-2

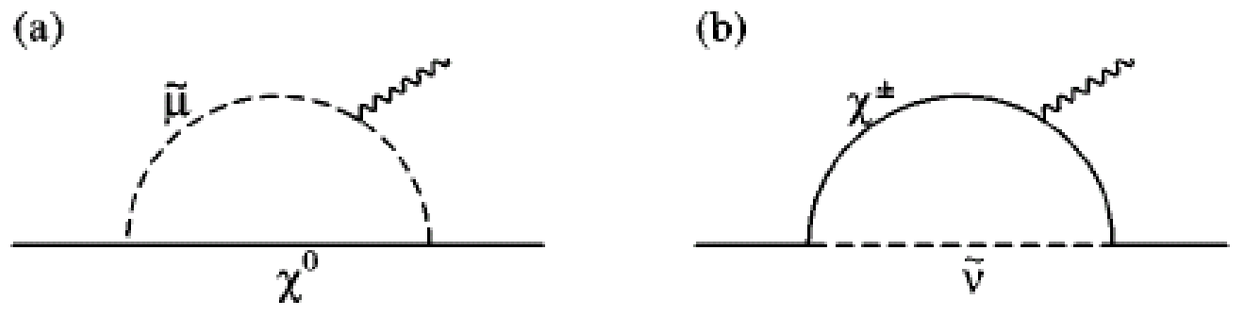


$$a_\mu = 11659208(6) \times 10^{-10}$$

$\mu^\pm$ combined 2.7σ



SUSY contributions



might suggest ?

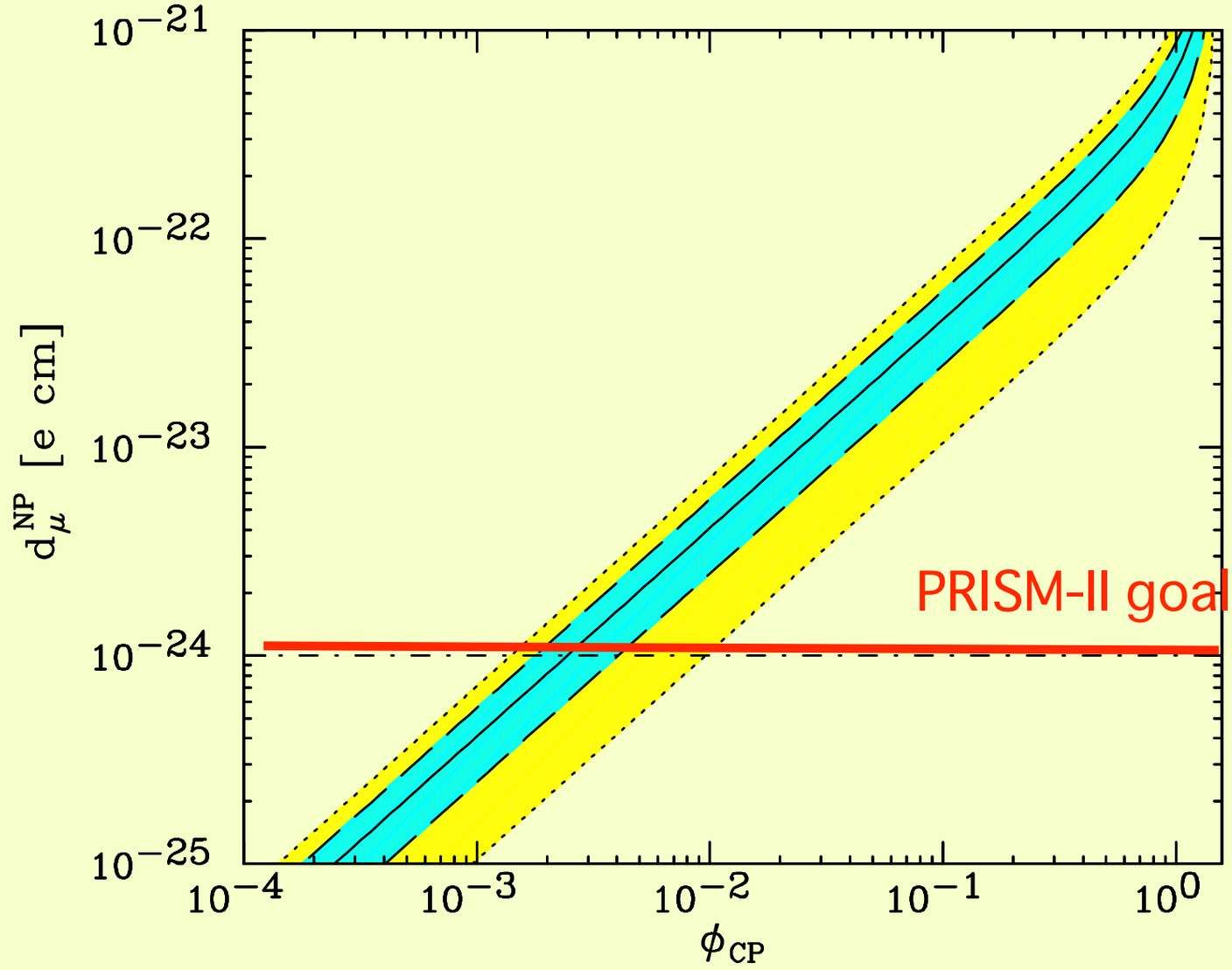
$$m_{\tilde{l}}^2 = \begin{pmatrix} m_{11}^2 & m_{12}^2 & m_{13}^2 \\ m_{21}^2 & m_{22}^2 & m_{23}^2 \\ m_{31}^2 & m_{32}^2 & m_{33}^2 \end{pmatrix}$$

Muon EDM

SUSY contribution to muon EDM

Muon (g-2)
and EDM might
be related.

hints for
leptogenesis



$d_\mu^{NP} \approx 3\times10^{-22}(\frac{a_\mu^{NP}}{3\times10^{-9}})\tan\phi_{CP}\ e\cdot cm,\ a_{NP} = a_\mu^{exp} - a_\mu^{SM} \approx 3(1)\times$

Feng, Matchev, Shadmi, NP B613, 366(2001)

The Muon Trio

Muon g-2

$$0.7\text{ppm} \rightarrow 0.05\ \text{ppm}$$

Muon LFV

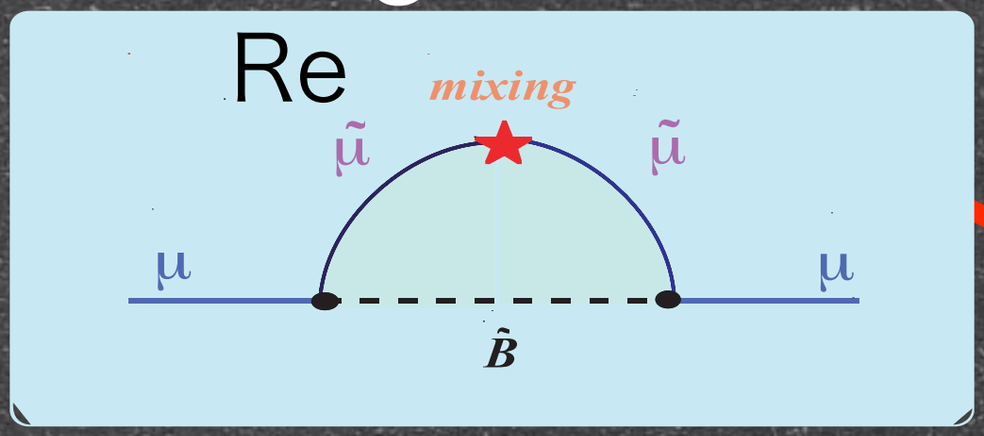
$$B(\mu^- N \rightarrow e^- N) < 10^{-18}$$

Muon EDM

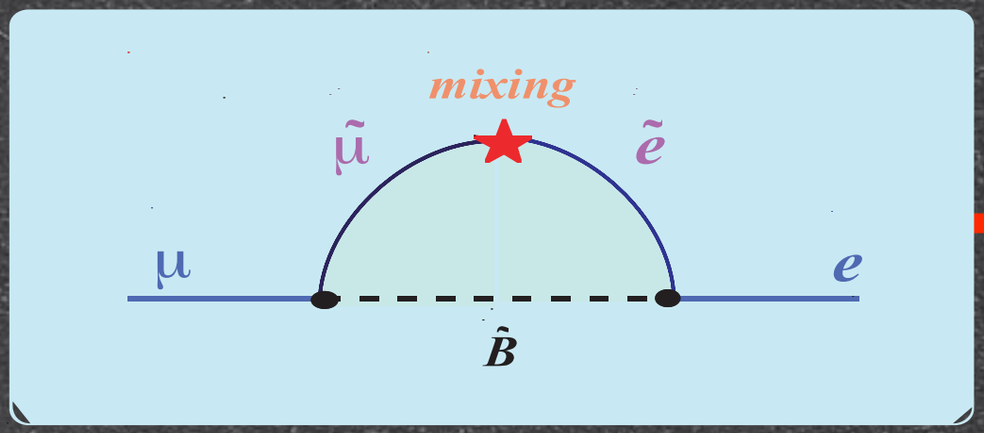
$$d_\mu < 10^{-19} e \cdot cm \rightarrow d_\mu < 10^{-24} e \cdot cm$$

The Muon Trio

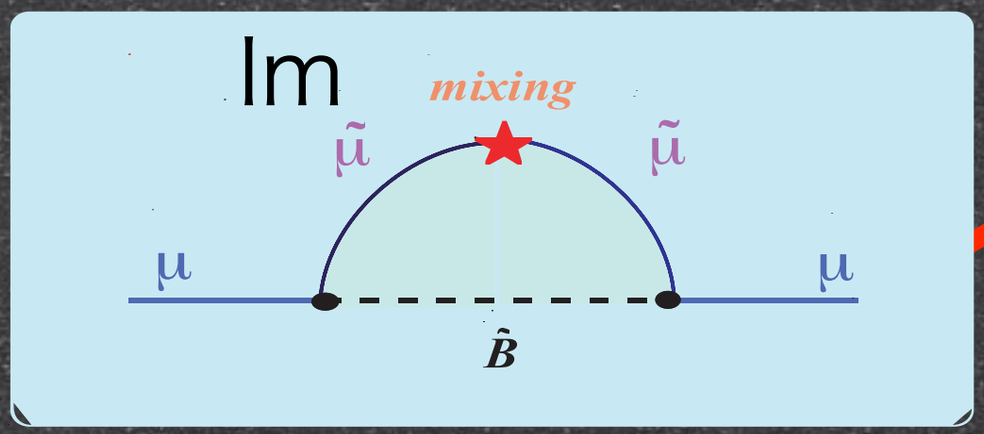
Muon g-2



Muon LFV



Muon EDM



in SUSY case

Slepton mixing matrix

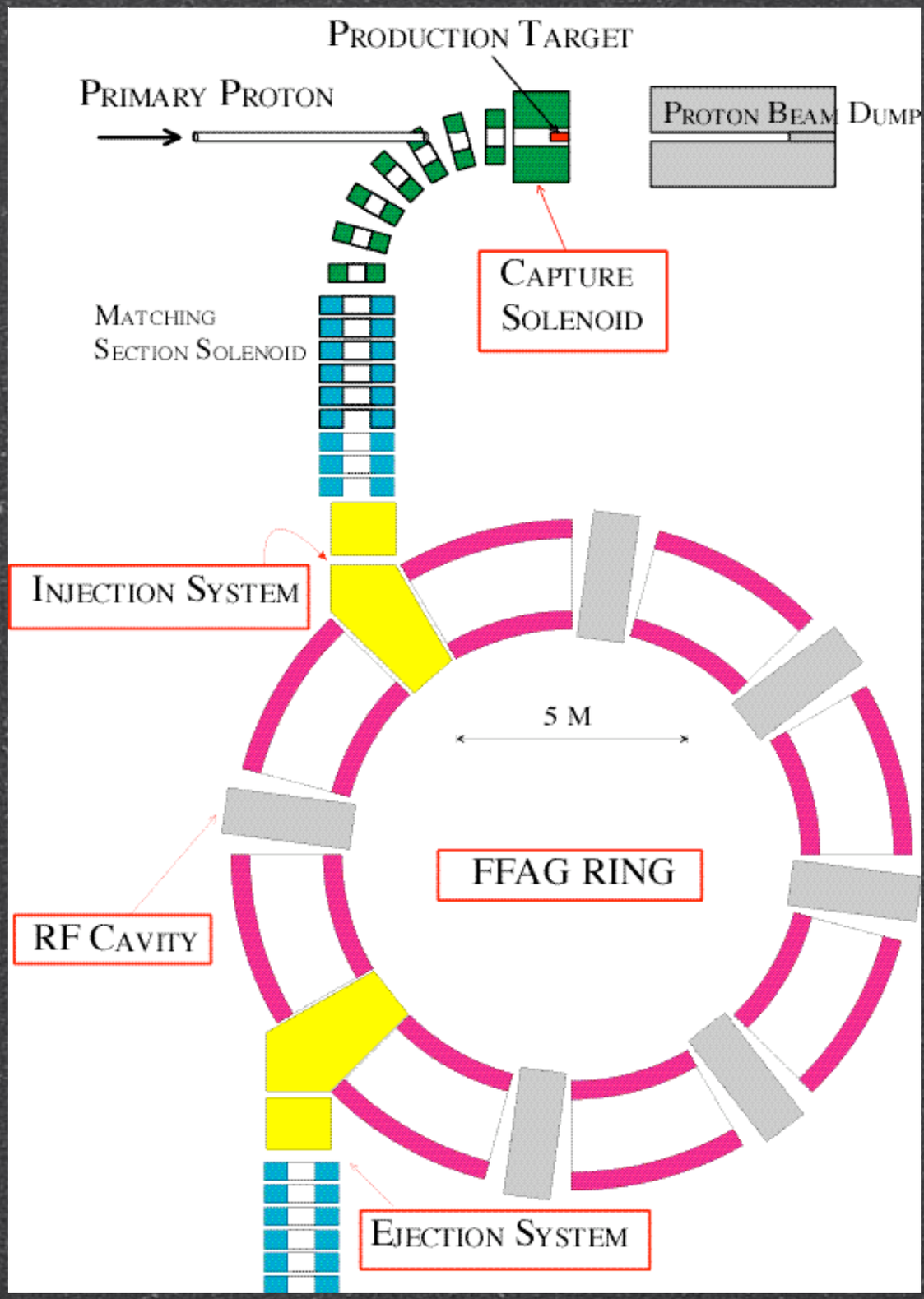
$$\begin{pmatrix} m^2_{\tilde{e}\tilde{e}} & \Delta m^2_{\tilde{e}\tilde{\mu}} & \Delta m^2_{\tilde{e}\tilde{\tau}} \\ \Delta m^2_{\tilde{\mu}\tilde{e}} & m^2_{\tilde{\mu}\tilde{\mu}} & \Delta m^2_{\tilde{\mu}\tilde{\tau}} \\ \Delta m^2_{\tilde{\tau}\tilde{e}} & \Delta m^2_{\tilde{\tau}\tilde{\mu}} & m^2_{\tilde{\tau}\tilde{\tau}} \end{pmatrix}$$

Hints for SUSY breaking

Muon Beams

PRISM

- PRISM: Phase Rotated Intense Slow Muon source
  - no pion contamination
  - small energy spread
  - beam extinction at PRISM kicker magnet
- PRIME experiment: aim for 10^{-18} sensitivity for μ–e conversion with the PRISM beam.



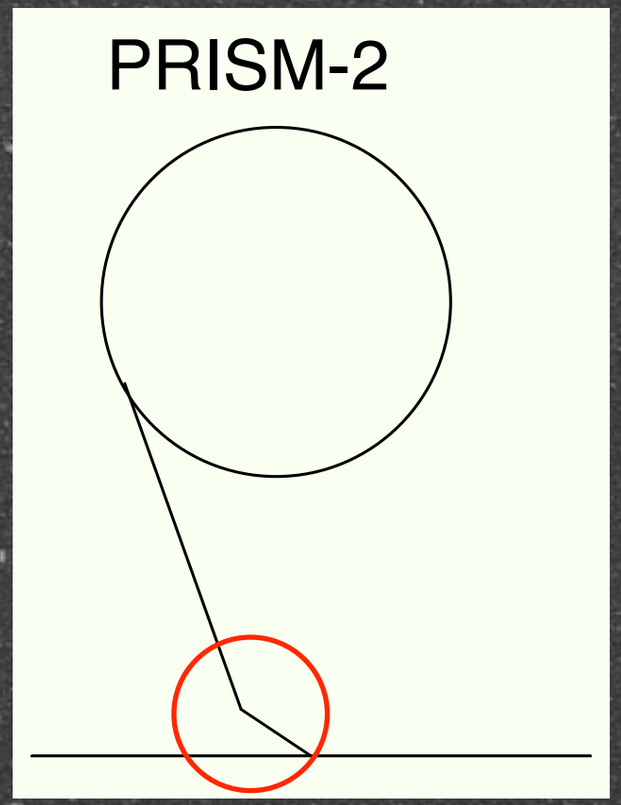
See Akira Sato's Talk.

PRISM-II for Muon EDM

PRISM-II = FFAG-based phase rotator for muon EDM

Requirements for 10^{-24} ecm

$NP^2 = 10^{16}$/year



Increase N (intensity)

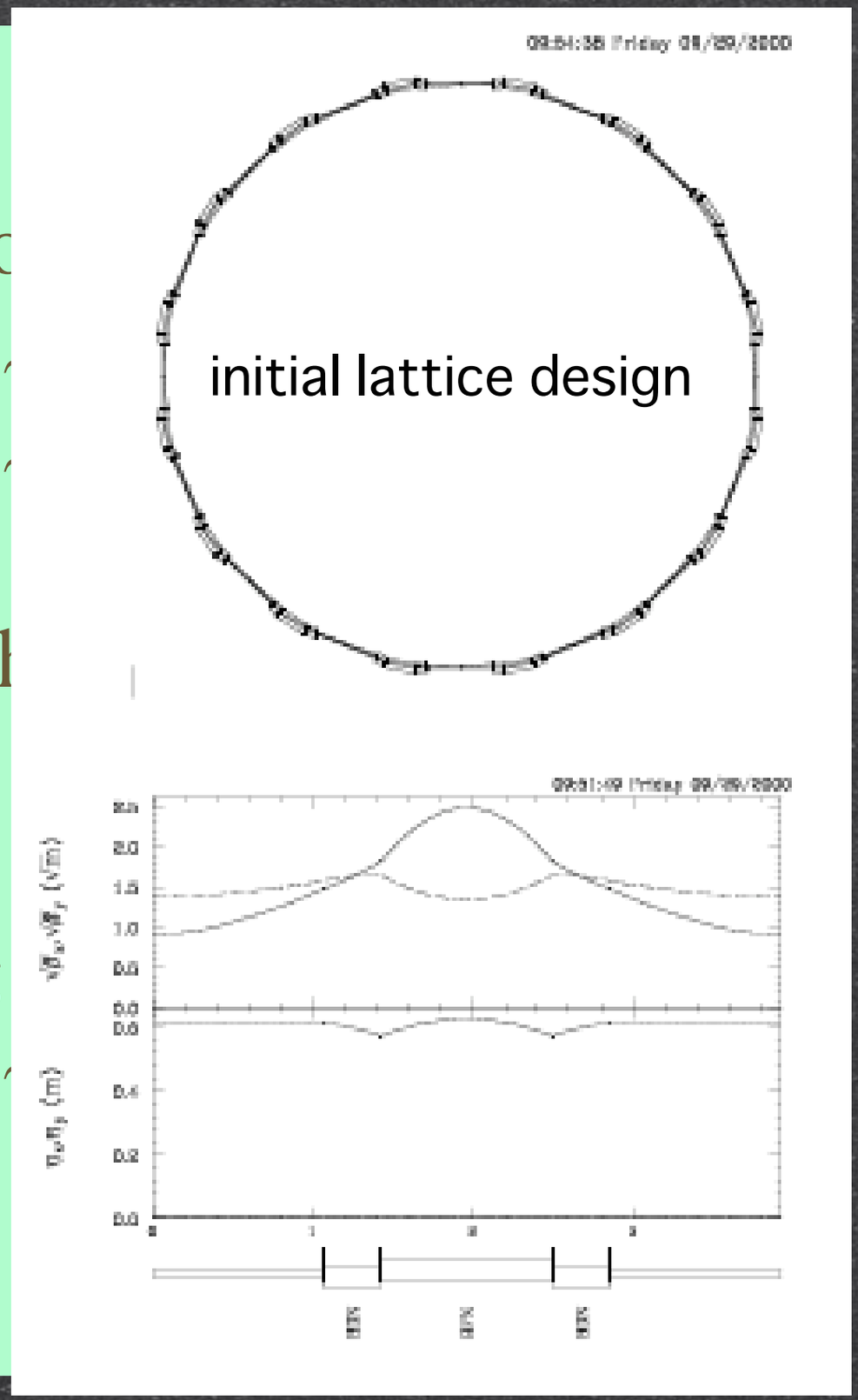
phase rotation to increase intensity within the given momentum band

Increase P (polarization)

curved solenoid to select (parent) pion momentum to keep reasonable muon polarization.

PRISM-II for Muon EDM

- $d_\mu < 10^{-24}$ e.cm → $NP^2 > 10^{16}$ total
- Long decay section with pion mo
  - Initial muon
  - Polarization
    - Backward decay of pions
- Accept 500 MeV/c muons and pl
  - Transverse 800 π mm.mrad
  - Momentum acceptance ±30%
    - →±1~2% for muon strage ring
  - Decay survivability
  - $NP^2 = 10^9 \sim 10^{10}$



Facility Layout Plan

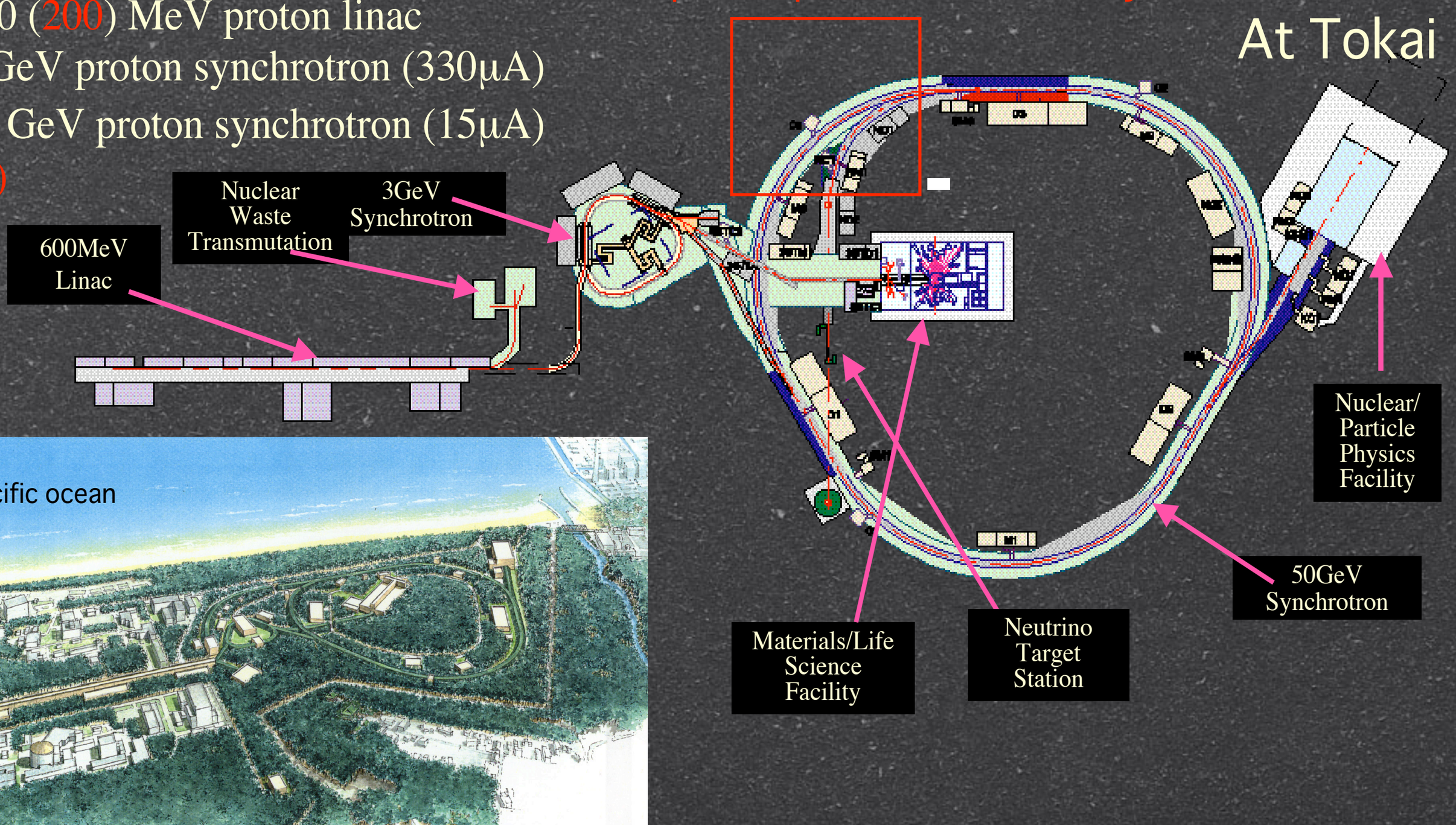
J-PARC at Tokai

J-PARC = Japan Proton Accelerator Research Complex

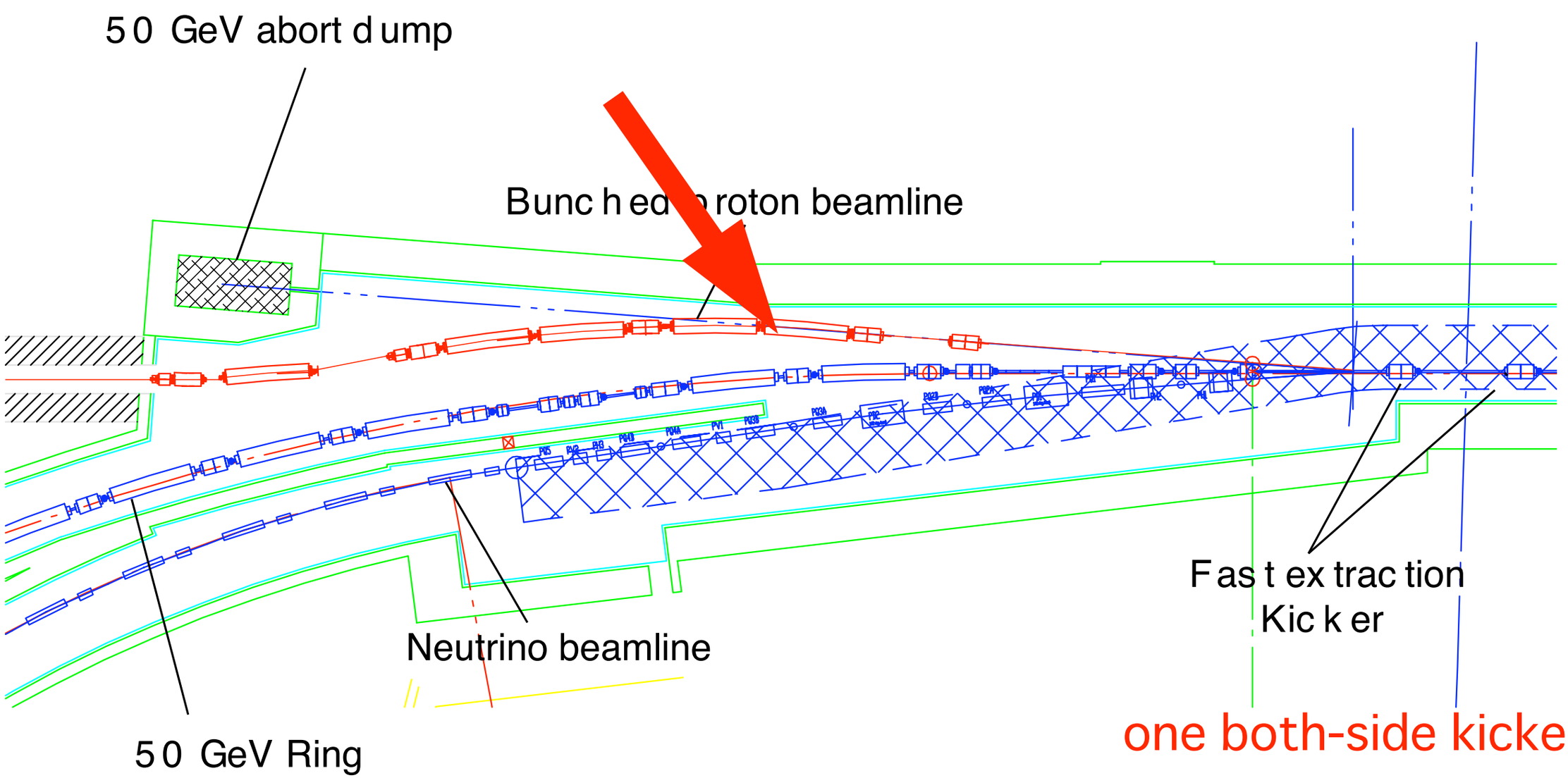
400 (200) MeV proton linac
3 GeV proton synchrotron (330μA)
50 GeV proton synchrotron (15μA)
(40)

pulsed proton beam facility

At Tokai



Proposed Fast Extraction



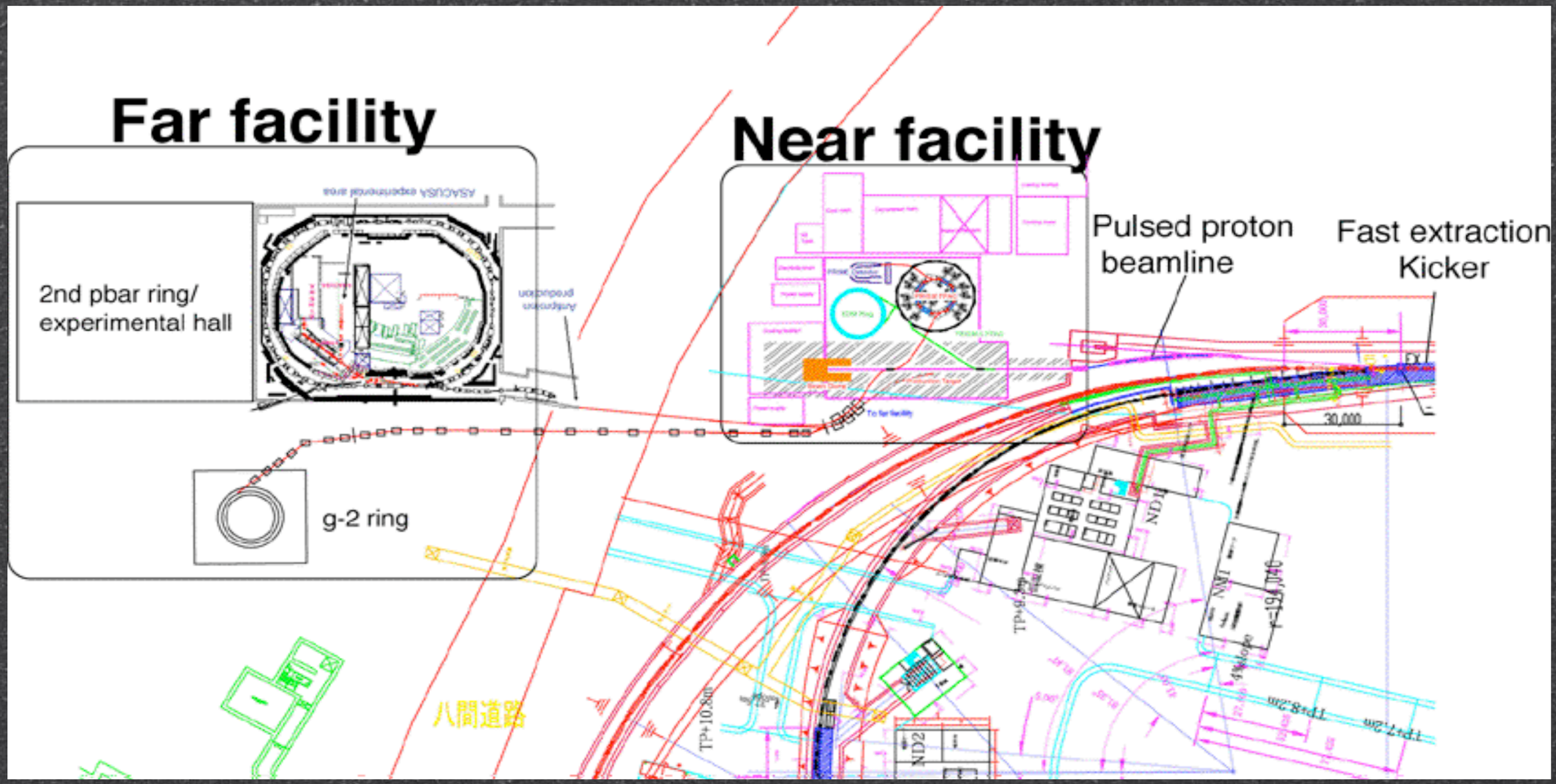
North-east side of the 50-GeV Ring

Muon Factory@J-PARC

Pulsed Proton Beam Facility is newly requested to J-PARC.

muon g-2
and anti-protons

PRISM and
PRISM-II(muon EDM)



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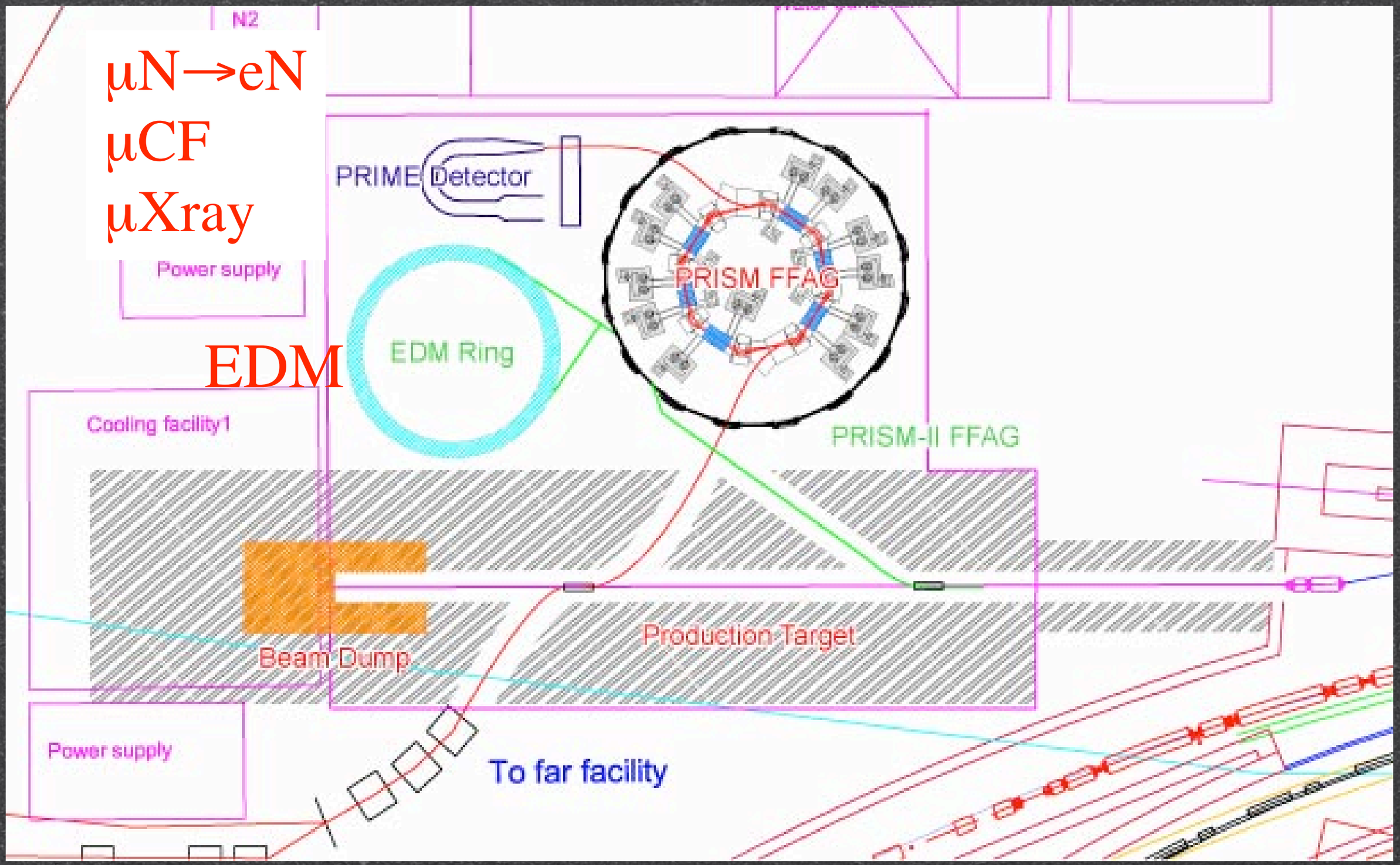


Proton Beam

Proton Beam Req.

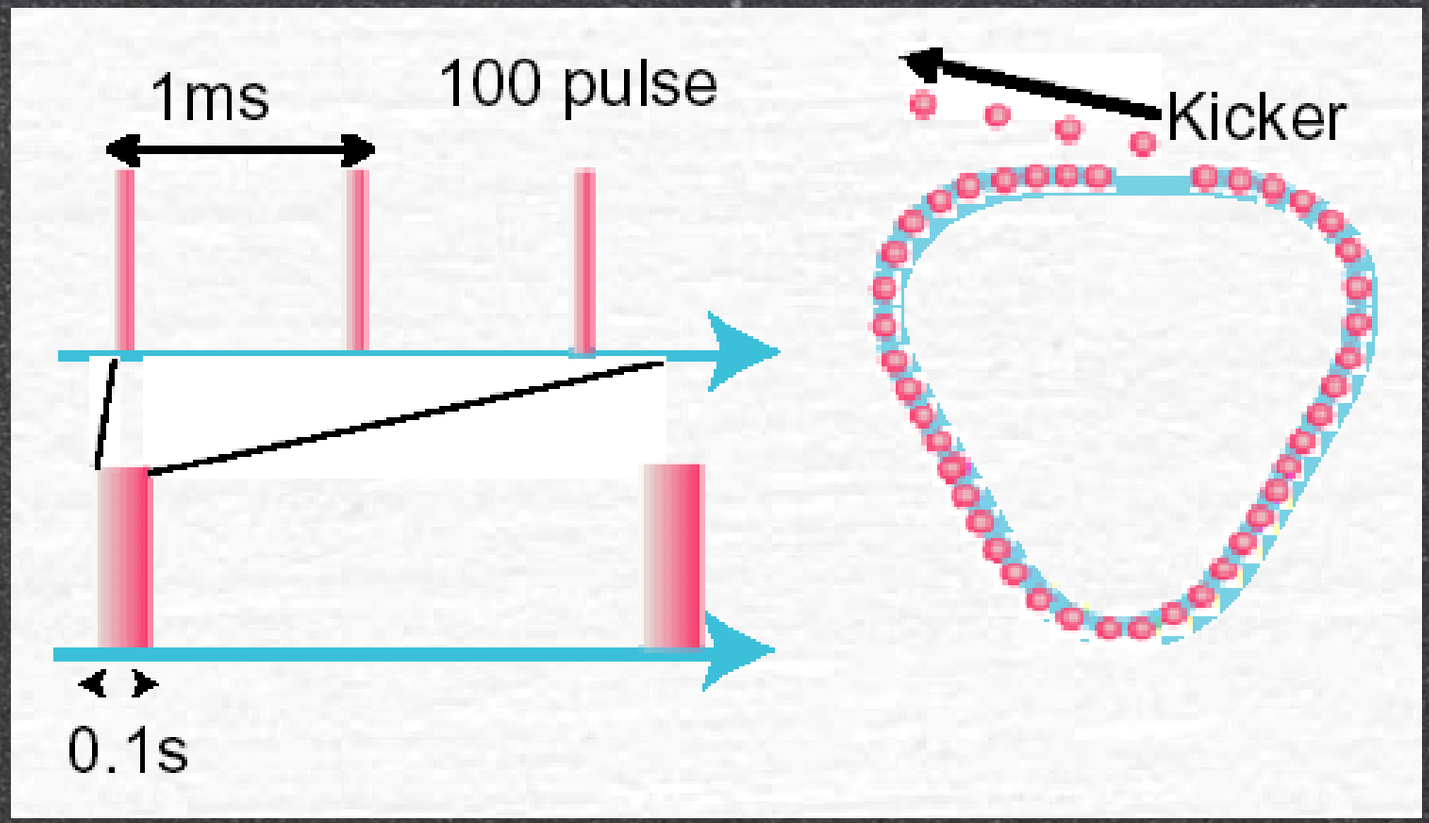
- Some muon programs need specific muon beam specifications, such as beam power (1MW more), time structure, instantan intensity, repetition, etc

	ti	p. rate
g-2		high
	low	high
	pulsed	
	DC	low	
μ→eee	DC	low	
lifetime	pulsed	low	high

Pulsed Proton Beam with high repetition should be needed for majority.

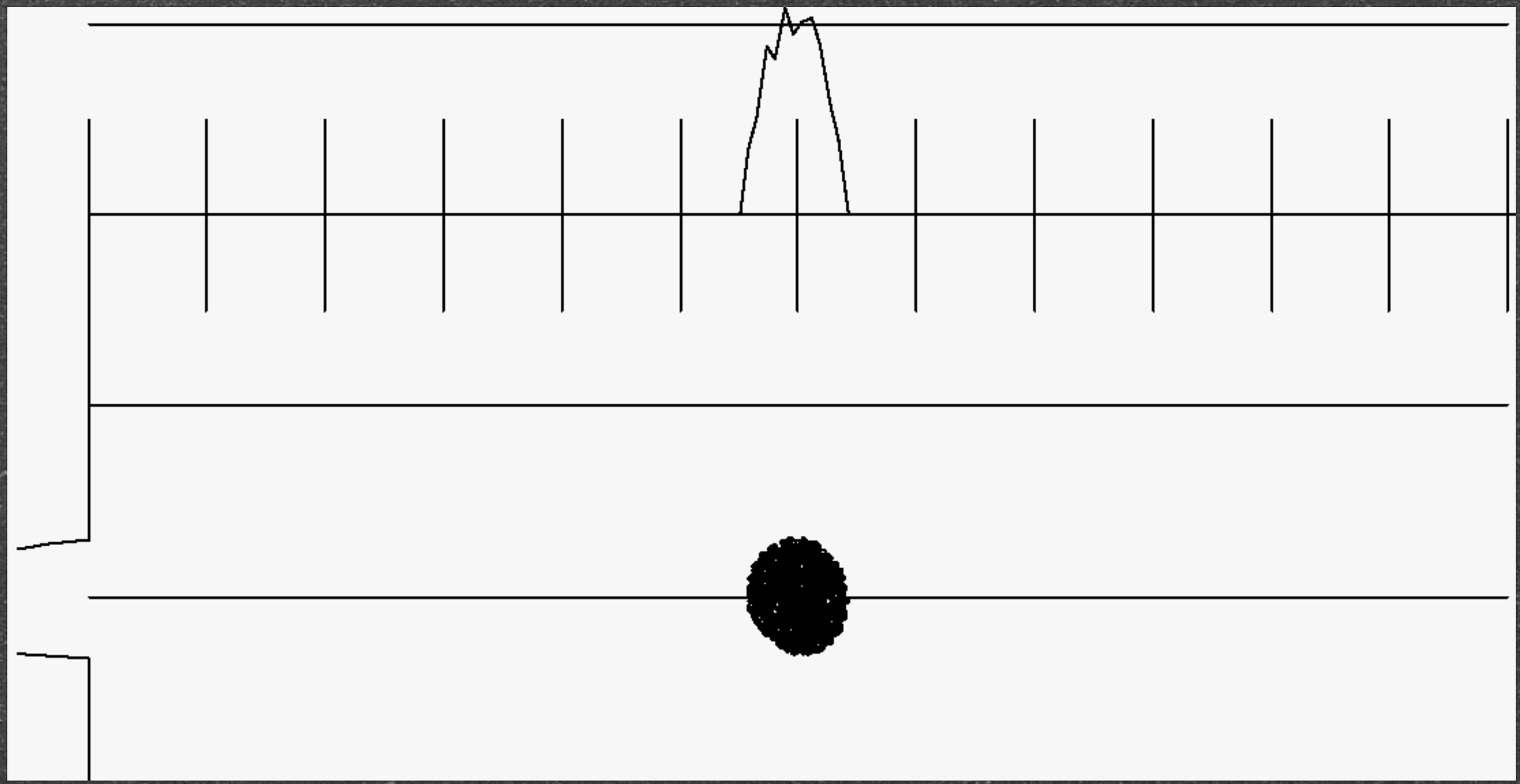
Multi Bunch Extraction

- debunch protons, then re-bunch them with higher hermonics (h=90 for instance).
  - large Vrf needed
- kick them in fast-extraction mode
  - fast rise/fall-off kicker magnet needed



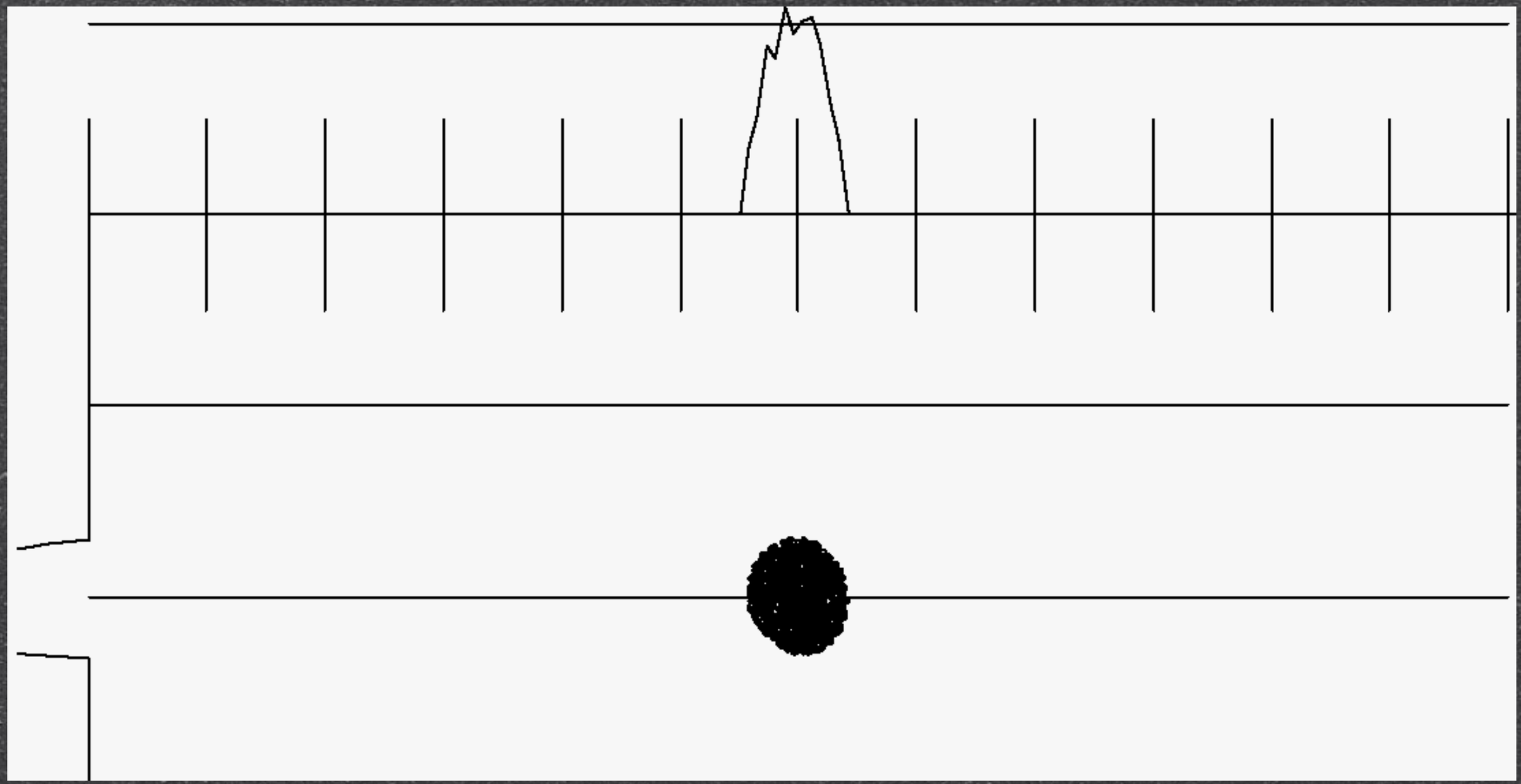
Re-bunching Simulation (1)

Re-bunching RF = 1 MV



Re-bunching Simulation (2)

Re-bunching RF = 3 MV



LOIs

LOI to J-PARC

Muon-related LOI List

	title	contact persons
1	The PRISM Project - A Muon Source of the World-Highest Brightness by Phase Rotation -	Y. Mori, K. Yoshimura, N. Sasao, Y. Kuno
2	An Experimental Search for the μ-e Conversion Process Towards an Ultimate Sensitivity of the Order of 10^{-18}	Y. Mori, K. Yoshimura, N. Sasao, Y. Kuno
3	Request for A Pulsed Proton Beam Facility at J-PARC	R.S. Hayano, Y. Kuno
4	A Study of Neutrino Factory in Japan	Y. Mori, Y. Kuno
5	Search for a Permanent Muon Electric Dipole Moment at 10^{-24} ecm Level	Y. Semertzidis, J. Miller, Y. Kuno
6	An Improved Muon (g-2) Experiment at J-PARC	L. Roberts
7	A Study of a Target System for a 4-MW, 50-GeV Proton Beam	K. McDonald, H. Kirk, Y. Kuno, Y. Yoshimura

reviewed in June, 2003

In J-PARC News Letter

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J-PARC Project Newsletter

_______ No. 14 November, 2003 _______

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1. <<Overview>> By Shoji NAGAMIYA

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On the other hand, for nuclear and particle physics experiments, presentations of 30 LoI's were made at two meetings in March and June. The results were sent to the Project Director. The committee recommended two important experiments for Day-1 at 50 GeV.
Also, the committee recommended the importance of a test beam line. About 16 experimental proposals were submitted for Phase 1 (but not for Day-1). The committee examined all the proposals carefully and ranked them. The Project Office is currently modifying the design of the experimental hall to allow important experiments for Day-1 and also in Phase 1. In addition to these proposals, many new proposals that require new beam lines were also submitted. They are classified as Phase 2+ experiments. Several excellent proposals were submitted in this Phase 2+ category. The project team decided to prepare a new second fast-extraction beam line in addition to the first fast-extraction beam line for the neutrino project.

LOI Evaluations

Aug. 2003

L25

An Experimental Search for the $\mu \rightarrow e$ Conversion Process at an Ultimate Sensitivity of Order of 10^{-18} with PRISM

Contact Persons: Y. Mori, K. Yoshimura, N. Sasao, and Y. Kuno

Schedule: Phase 2+

Comments:

This LoI describes an experiment called PRIME, which is designed to search for the Lepton-Flavor-Violating (LFV) $\mu \rightarrow e$ conversion process. Discovery of a signal in this mode would have enormous impact and would constitute unambiguous evidence of physics beyond the standard model. PRIME's target sensitivity of 10^{-18} in branching ratio provides sensitivity to a large portion of the available parameter space of various supersymmetric extensions to the standard model.

The committee rates the physics goals of PRIME extremely high and recommends that it be considered as a Phase II proposal.

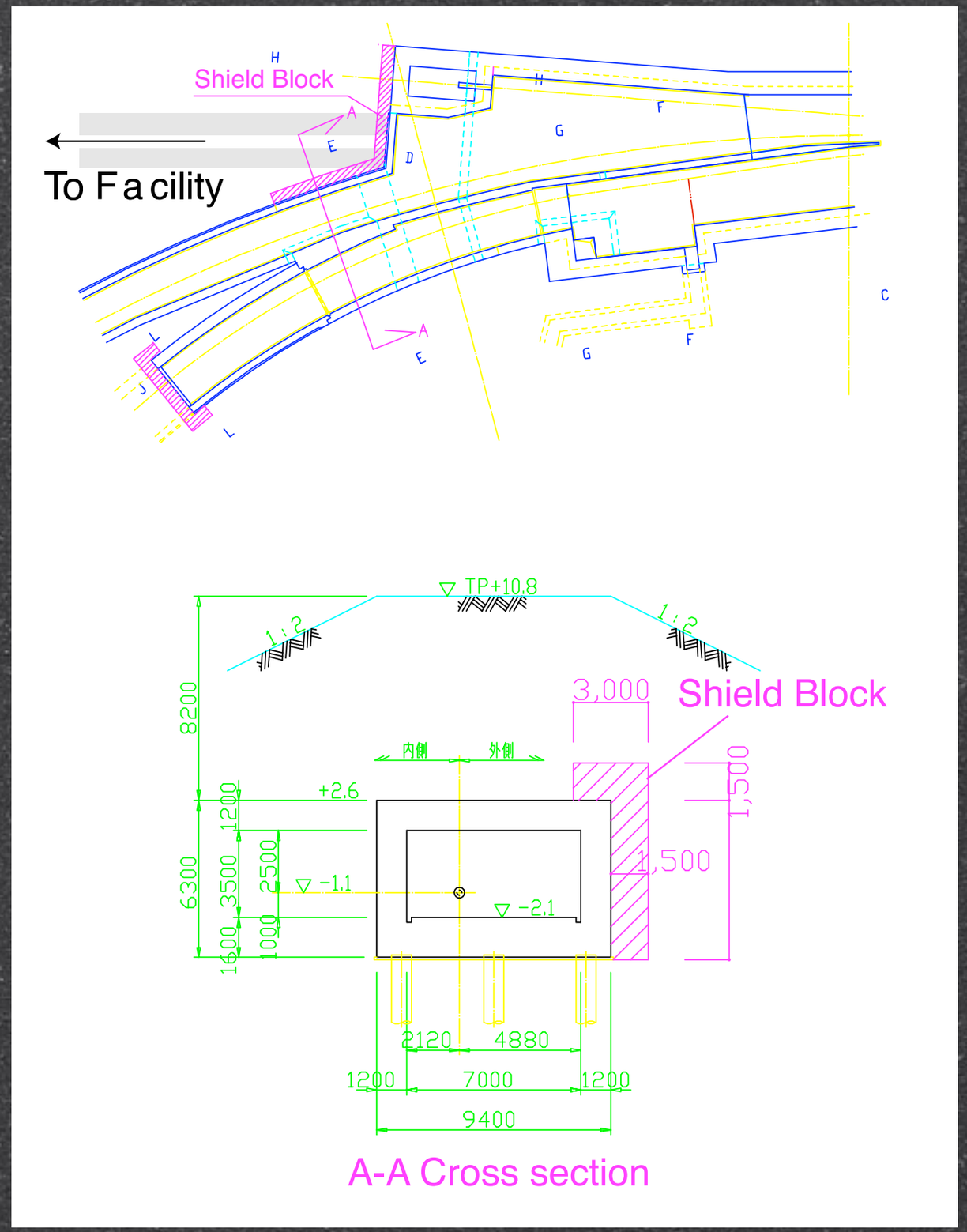
J-PARC Phasing

- Phase-1 (2001-2008)
  - J-PARC original budget : about 190 B JYen
  - 135 B JYen approved in JFY2001 : Phase-1
  - will be completed by spring, 2008.
- Phase-1.5? (2004-2008)
  - Neutrino Program approved in JFY2004 (16 B JYen) for 5 years
- Phase-2
  - Rest in the original budget
- Phase-3
  - something new

Phase 2+

Status in JFY2004

- At J-PARC Phase-1, we have requested budget for shielding to prevent soil activation for the proposed pulsed-proton beam line (2003, LOI).
- In JFY2004, we receive from KEK about 25 M JYen. The shielding will be constructed and placed.



More Works to do...

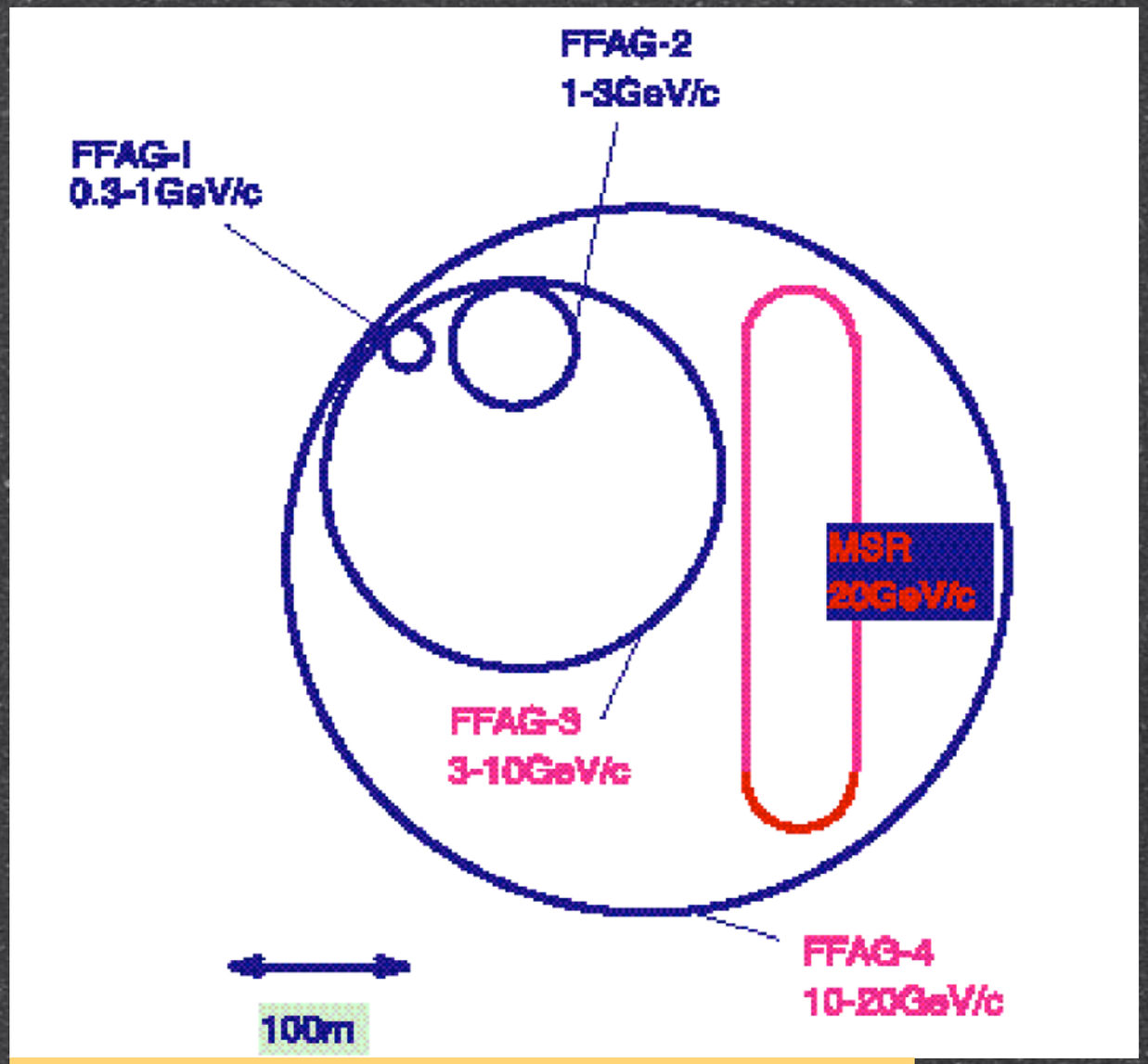
- Study of multi proton bunching scheme in the J-PARC 50-GeV ring
- R&D on Fast proton kicker magnet
- Design of the proton beam line optics
- Targetry
- Cost Estimation of the Facility
-
- Preparation for Proposal Call ?

Future Extension

FFAG-based Acceleration

- FFAG
  - Large acceptance
  - Fast acceleration
  - Muon cooling is not mandatory (better if available).
- Advantages
  - less RF cavities and power.
  - simple and compact
- Either Scaling or Non-scaling !!!

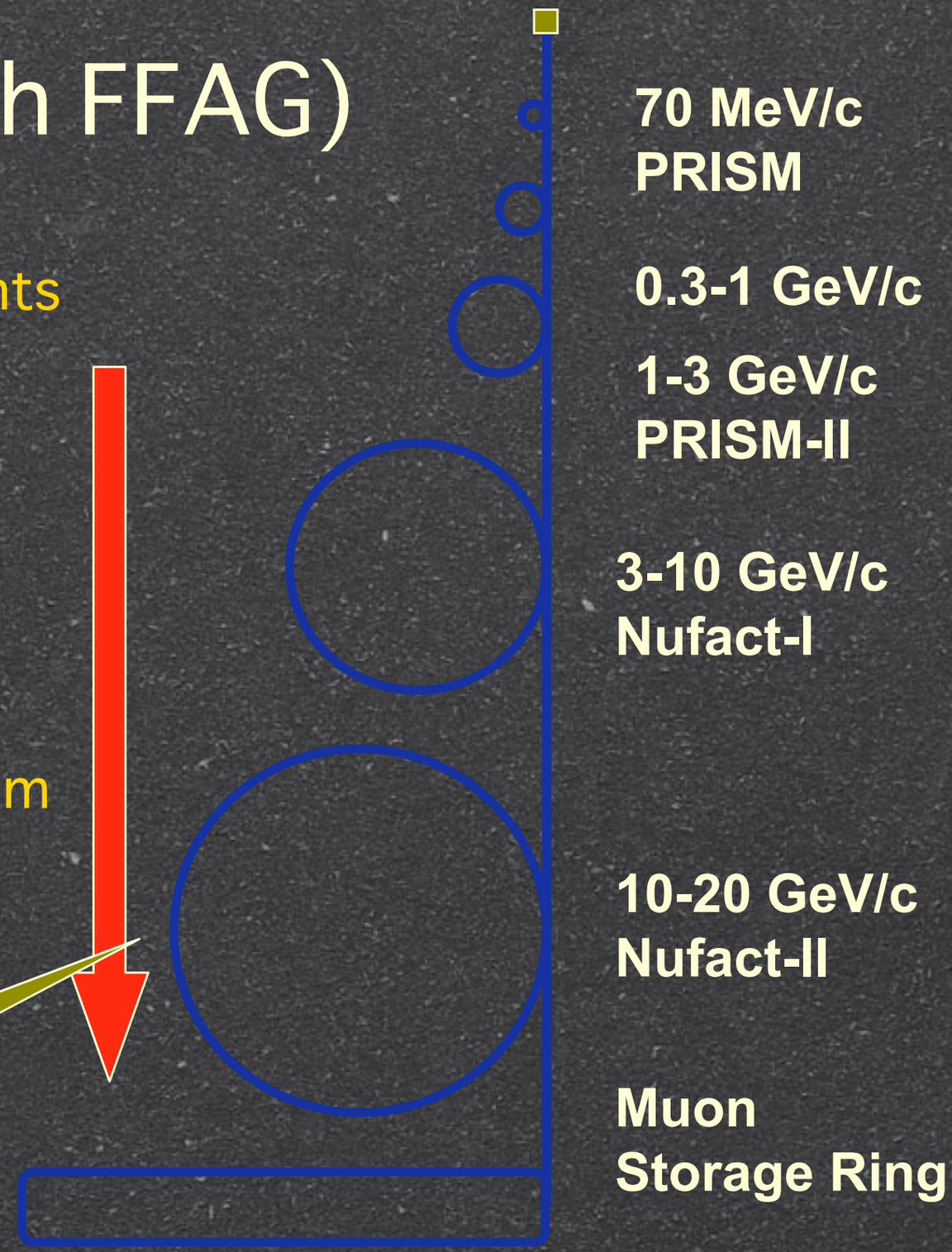
A series of 3-4 FFAG rings



Muon Acceleration based on a series of FFAGs

From MF to NF

- Staging scenario (with FFAG)
  - Muon Factory (PRISM)
    - For stopped muon experiments
  - Muon Factory-II (PRISM-II)
    - Muon moments (g-2, EDM)
  - Neutrino Factory-I
    - Based on 1 MW proton beam
  - Neutrino Factory-II
    - Based on 4.4 MW proton beam
  - Muon Collider



Physics outcome at each stage

Summary

- The muon facility at J-PARC (muon factory) is proposed.
  - Various muon programs, such as muon g-2, muon EDM, muon LFV, are considered.
  - Innovative muon beams are studied and R&Ded, such as PRISM, PRISM-II.
- Proton beam studies and the cost estimation of the whole facility should be made.
- We will request funding of the muon facility to the phase-II of J-PARC.
- The Fermilab opportunity is also welcome.